2010 March 15

Testimony before the House Science Committee by
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Mr. Chairman, distinguished members, thank you for the opportunity to appear today to discuss research and governance related to the issue of geoengineering.

I am Granger Morgan, Professor and Head of the Department of Engineering and Public Policy at Carnegie Mellon University. I hold a Ph.D. in applied physics and have worked on a range of the technical and policy aspects of climate change for roughly 30 years.

When we were awarded a large NSF grant to create The Center for Integrated Study of the Human Dimensions of Global Change, in 1995, one of the early things we did was to conduct a review of the state of knowledge in geoengineering. My colleagues Hadi Dowlatabadi and David Keith published several papers as a result, including:

- David W. Keith, "Geoengineering the Climate: History and Prospect," *Annual Review of Energy and the Environment*, 25, pp. 245-284, 2000.
- David W. Keith and Hadi Dowlatabadi, "A Serious Look at Geoengineering, *Eos, Transactions American Geophysical Union*, 73, pp. 289-293, 1992.

After this initial work we moved on to other topics, and I did not think seriously about geoengineering again until about three years ago. At that time the foreign policy community was largely unaware of the possibility that humans might be able to rapidly increase earth's albedo (the fraction of sunlight reflected back into space) by roughly one percent and in so doing offset the warming caused by carbon dioxide and other greenhouse gases. The Royal Society had recently termed such activity SRM, or "solar radiation management."

In reflecting on the dismayingly slow pace of progress the world was making in cutting emissions of carbon dioxide, I began to be concerned that there is a growing risk that large effects from climate change might occur somewhere in the world that could induce a nation or group of nations to unilaterally modify the albedo of the planet in order to offset rising temperature. If someone were to do that, it could impose large effects on the entire planet.

In order to start a conversation with the foreign policy community I enlisted four colleagues (two like me with backgrounds in physics and planetary science backgrounds and two with backgrounds in political science and foreign policy). We organized a workshop at the Council on Foreign Relations (CFR) here in Washington, DC on May 5, 2008. We had excellent attendance from senior folks in both the science and foreign policy communities.

The five of us subsequently published a paper in the journal *Foreign Affairs* that summarized our thinking at that time:

- David G. Victor, M. Granger Morgan, Jay Apt, John Steinbruner, and Katharine Ricke, "The Geoengineering Option," *Foreign Affairs*, *88*(2), 64-76, March/April 2009. (Attachment 1)

Because the CFR workshop involved only North Americans, and because this is a global issue, I subsequently organized a second more international workshop, again with the objective of stimulating discussion between the scientific and foreign policy communities. This second workshop was hosted by the Government of Portugal on April 20-21, 2009. Participants in this second workshop came from North America, from across the EU, and from China, India and Russia.

SRM has five key attributes:

1. It is fast (i.e. cooling could be initiated in months not decades).
2. It is likely to be relatively inexpensive (i.e. as much as 100 to 1000 times cheaper than achieving the same temperature reduction through a systematic reduction of global emissions of carbon dioxide).
3. It will be imperfect (i.e. it will do nothing to offset the effects of rising carbon dioxide levels on ocean acidification and the associated destruction of coral reefs and ocean ecosystems; it will dry out the hydrological cycle – and while recent studies indicate it will move temperature and precipitation back closer to what they were before climate change, it will not do so perfectly and there will be differences in how well it will work in different parts of the world); it will not offset impacts from elevated concentrations of carbon dioxide on terrestrial ecosystems.
4. Once started, if SRM is ever stopped, and carbon dioxide emissions have continued to rise, the resulting rapid increase in temperature would result in catastrophic ecological effects.
5. Unlike emission reduction which requires cooperation by all large emitters, a single nation (indeed, perhaps even a single very wealthy private party) could undertake SRM and effect the entire planet.

Up until now there has been very little serious research conducted on strategies to modify rapidly the albedo of the planet (i.e. on SRM). Historically, most folks in the climate science community have been reluctant to work in this area for two reasons:

- they did not want to deflect scarce funding and attention from the very important task of improving our understanding of the climate system;
- they were worried that if we better understand SRM and how to do it, that might deflect attention away from reducing emissions, and might also increase the probability that someone would actually engage in SRM.

I want to emphasize in the strongest possible terms that I am *not* arguing that the U.S. or anyone else should engage in SRM. We need to get much more serious about achieving a dramatic reduction in emissions of carbon dioxide.

However, because I believe that we are getting closer to the time when someone might be tempted to unilaterally engage in SRM in order to address local or regional problems caused by climate change, or a situation in which the world faces a sudden and unexpected climate emergency that places large number of people at risk, I think we have passed a tipping point. In my view, the risks of not understanding better whether and how SRM might work, what its intended and unintended consequences might be, and what it might cost, are today greater than the risks associated with doing such research. My colleagues and I have spelled out these arguments in two recent publications:

- David W. Keith, Edward Parson and M. Granger Morgan, "Research on Global Sun Block Needed Now," *Nature*, *463*(28), 426-427, January 2010. (Attachment 2)
- M. Granger Morgan, "Why Geoengineering?," *Technology Review*, 14-15, January/February 2010.

With this background, I turn now to two questions which I understand this Committee is especially interested: who should fund research and what approach should be taken to issues of governance.

Up until now my remarks have been exclusively about SRM. There are a number of technologies for directly scrubbing carbon dioxide the earth's atmosphere and sequestering it deep underground. In my view, these are very important, and deserve considerably expanded research support, but do not pose significant issues of global governance. While slow, this approach is particularly attractive because it gets to the root of the problem by reducing the amount of carbon dioxide in the atmosphere. Thus, unlike SRM it also addresses ecosystem risks such as ocean acidification.

I believe that the Department of Energy should support research to develop and test technology to directly scrub carbon dioxide from the atmosphere at a level starting at several tens of millions of dollars per year. I do not believe that more than modest support is warranted for other strategies to remove carbon dioxide from the atmosphere.

As with power plants with carbon capture (CCS), once carbon dioxide has been captured it must be disposed of. At the moment, the best alternative is to do this via deep geologic sequestration. There are significant regulatory challenges for such sequestration. At Carnegie Mellon, we anchor the CCSReg project that is developing recommendations on the form that such regulation should take. Details are available on the web at www.CCSReg.org and are summarized in Attachment 3.

With respect to SRM, I believe that initial research support should be provided via NSF beginning at a level of a few million dollars per year. Indeed, both the policy and scientific work that I and my colleagues and Ph.D. student (Katharine Ricke) have been doing in this area have been conducted with support from NSF.

I argue that NSF should be the initial funding agency for two reasons:

1. NSF does a good job of supporting open investigator initiated research and we need a lot of bright people thinking about this topic from different perspectives in an open and transparent way before we get very far down the road of developing any serious programs of field research.
2. In addition to natural science and engineering, NSF supports research in the social and behavioral sciences. Perspectives and research strategies from those fields needs to be brought to bear on SRM as soon as possible.

We will not be able to learn everything we need to learn with laboratory and computer studies. Once it becomes clear that we need to be doing some larger scale field studies, then it would be appropriate to engage NASA and or NOAA. In addition to small scale field studies, it may also be possible to learn through more intensive studies of the "natural SRM experiments" that occur from time-to-time when volcanoes inject large amounts into the stratosphere. NSF, NASA or NOAA would all be able to prepare instrumentation and research plans to study such events, and should be encouraged to do so.

I would argue against involving DoE. They need to stay focused on the problems of decarbonizing the energy system.

While private funding should be encouraged for research and development of technologies to scrub carbon dioxide out of the atmosphere, steps should be taken to strongly discourage private funding for SRM since that holds the potential to create a special interest that might push to move past research to active deployment.

I believe that any research in SRM should be open and transparent. For this reason, and for reasons of international perceptions, I argue strongly that research on SRM should *not* be undertaken by DOD or by the intelligence communities.

Finally, I turn to the issue of global governance and SRM – the subject of the two workshops I described above. People do lots of things in the stratosphere today, most of which are pretty benign. So long as it is public, transparent, and modest in scale, and informally coordinated within the scientific community (e.g. by a group of leading national academies, the international council of scientific unions (ICSU), or some similar group) I believe there should be no constraints on modest low-level field testing, done in an open and transparent manner, designed to better understand what is and is not possible, what it might cost, and what possible unintended consequences might result.

That said, I think it likely that pressure will grow for some more formal international oversight. For that reason I think one of the first objectives in a U.S. research program should be to give the phrase "modest low-level field testing" a more precise definition. Figure 1 illustrates one way to think about this issue. In this diagram X, Y and Z define the limits to an "allowed zone." They refer respectively to upper bounds on the amount of radiative forcing that an experiment could impose, the duration of that forcing, and the possible impact on ozone depletion (the surface of particles can provide reaction sites at which ozone destruction could occur).

Initial research should explore whether these three axis are the right ones, or whether there should be other or additional dimensions.

The "allowed space" might not be a simple cube. For example, as Figure 2 suggests, if the scientific community thought it was important to test a small number of particles that because of special properties would be very long lived, but would have de minimus effect on planetary forcing or ozone depletion, a more complex "allowed space" might be called for.

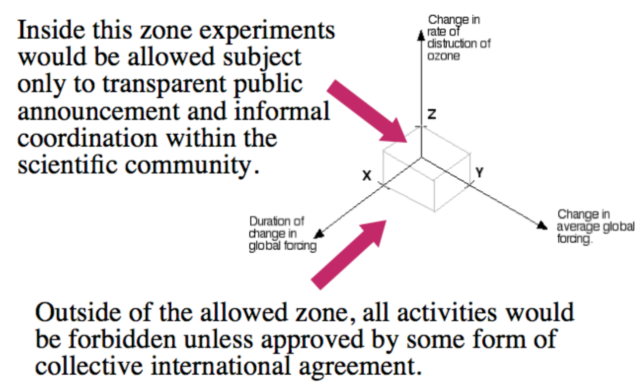


**Figure 1:** A possible strategy for defining a "space" in which experiments can be run only with transparency and informal coordination across the scientific community.

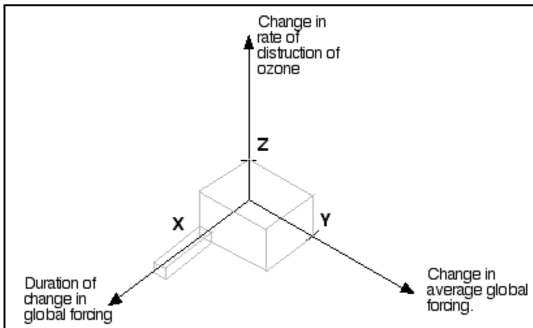


**Figure 2:** The shape of the "allowed zone" that makes the most sense scientifically may not be simple and should be the subject of careful early research.

I am not prepared to argue that there should be a formal treaty any time soon that addresses these issues. However, I think there is a good chance that pressure will grow for some form of international agreement (perhaps just an agreement among major states that others can choose to sign on to). For this reason we should start now to lay the scientific foundation for defining such an "allowed space." If work has not been done before hand it might be very hard to introduce a reasoned scientific argument if political momentum grows for serious limitations – perhaps even an outright ban or "taboo." For this reason I think we should continue to promote discussion between the scientific and foreign policy communities about what form(s) of international agreement and enforcement (if any) would be most appropriate and what sorts of scientific foundation they would require.

Attachments:
1. "The Geoengineering Option" from *Foreign Affairs*, 2009.
2. Opinion piece "Research on Global Sun Block Needed Now" from *Nature*, 2010.
3. Summary of regulatory recommendations for deep geological sequestration of carbon dioxide from the **CCSReg** project.
4. Bio for M. Granger Morgan.

**ATTACHMENT 1**

David G. Victor, M. Granger Morgan, Jay Apt, John Steinbruner, and Katharine Ricke, "The Geoengineering Option," *Foreign Affairs*, *88*(2), 64-76, March/April 2009.

**Summary***:* Global warming is accelerating, and although engineering the climate strikes most people as a bad idea, it is time to take it seriously.

*Full paper can be found at:*
http://www.foreignaffairs.com/articles/64829/david-g-victor-m-granger-morgan-jay-apt-john-steinbruner-and-kat/the-geoengineering-option

**ATTACHMENT 2**

David W. Keith, Edward Parson and M. Granger Morgan, "Research on Global Sun Block Needed Now," *Nature*, *463*(28), 426-427, January 2010.


**Summary**

- Field testing is required to understand the risks of solar-radiation management (SRM)
- Linked activities must create norms and understanding for international governance of SRM
- If SRM is unworkable, the sooner we know, the less moral hazard it poses


*Full paper can be found at:*
http://www.nature.com/nature/journal/v463/n7280/full/463426a.html

**ATTACHMENT 3**

# Developing a U.S. Regulatory Framework for CCS: A Summary of Recommendations from the CCSReg Project

Sean T. McCoy, Carnegie Mellon University

Carbon capture and sequestration (CCS) technology has the potential to contribute to a significant reduction in emissions of carbon dioxide ($CO_2$) from power generation and other industrial sectors if it can be deployed widely. While there are still significant technical challenges to be overcome, in the United States (U.S.) the absence of a consistent and predictable legal and regulatory framework to govern its use presents a serious obstacle to rapid and wide adoption.

In contrast to much of the world, where the deep pore space used in geologic sequestration is the property of the nation or the "crown," questions of ownership are based on myriad legal precedents that vary from one U.S. state to another. Operators in the U.S. inject large quantities of fluid waste underground under the U.S. Environmental Protection Agency's (EPA) Underground Injection Control (UIC) program without securing permission from surface landowners. Indeed, municipalities in Florida inject roughly 3 Gt/year of treated wastewater. However, absent law clarifying whether use of pore space for GS will require compensation, the moment an operator begins to inject $CO_2$, we anticipate that litigants will appear demanding compensation.

The other serious obstacle involves issues of long-term stewardship: who has responsibility for monitoring and remediation closed sites and who assumes the associated liability. The insurance industry is poised to insure all phases of a CCS project up until a closed project goes into long-term stewardship, but is not prepared to write policies that extend beyond that time.

Because it is operating under authority provided by the Safe Drinking Water Act, the EPA's current proposal to regulate CCS through the creation of a new well class under the UIC program, is not able to address either of these, or other key problems.

The CCSReg project was created to develop proposals that address these and other legal and regulatory barriers facing CCS in the U.S. Anchored in the Department of Engineering and Public Policy at Carnegie Mellon University, the project involves co-investigators at the Vermont Law School, and the Washington, DC law firm of Van Ness Feldman, and at the University of Minnesota. The project released an interim report that framed the issues in January of 2009.

The CCSReg project has now released six policy briefs that outline how the project believes the key regulatory issues should best be resolved in a U.S. context. These briefs address the overall structure that comprehensive regulation of CCS should take; the regulatory framework for pipelines transporting $CO_2$ for CCS; governing access to and use of pore space in geologic sequestration; managing liability and long-term stewardship for geological sequestration; and accounting for $CO_2$ sequestered through CCS.

Although some of the recommendations are included in the American Clean Energy and Security Act of 2009 and other pending state and federal legislation, the briefs take a more comprehensive look at an entire program for regulation of CCS.

Specific recommendations from these briefs include:

- Amend the U.S. Safe Drinking Water Act to direct Underground Injection Control (UIC) program regulators to create adaptive, performance-based rules for geologic sequestration, and to include mechanisms to resolve conflicts between multiple environmental objectives.
- Expand the federal UIC program to address conflicting uses of pore space during permitting; creating new federal legislation that would limit the trespass liability of a sequestration project developer operating pursuant to a valid UIC permit.
- Modify the U.S. Federal Land Policy Management Act to specifically authorize the use of federal lands for geologic sequestration.
- Create a Federal Geologic Sequestration Board ("FGSB") that would oversee long-term stewardship of properly closed sequestration projects.
- Create a revolving fund, based upon risk-based assessments on geologic sequestration projects during their operating life, which will finance the FGSB and any remediation or compensation necessary during long-term stewardship.
- Create a stop-gap federal indemnity program for the stewardship phase of "first-mover" geologic sequestration projects.
- Treat sequestered $CO_2$ as avoided emissions rather than offsets and require each component of a CCS project (i.e. capture, transport, and sequestration facilities) to report the amount of $CO_2$ handled.
- Require focused surface monitoring to locate and quantify atmospheric leakage only if subsurface monitoring indicates $CO_2$ has migrated through the confining formation and either surface monitoring of vegetation or soil gas detects leakage.
- Develop an "opt-in" federal regulatory regime providing the U.S. Federal Energy Regulatory Commission authority to grant or deny applications for federal siting permits for new $CO_2$ pipelines built for the purposes of geologic sequestration.

Forthcoming briefs in this series will address criteria for permitting and closure of geologic sequestration sites; removing commercial barriers to deployment of CCS technology; and managing the transition from Enhanced Oil Recovery to geologic sequestration.

The five briefs discussed here, the forthcoming briefs in the series, and other publications from the project are available at http://www.ccsreg.org.

Primary support for the CCSReg project is provided by a grant from the Doris Duke Charitable Foundation. Additional support is provided by the Climate Decision Making Center through a cooperative agreement between the National Science Foundation (SES-0345798) and Carnegie Mellon University.

## ATTACHMENT 4

**M. Granger Morgan** is Professor and Head of the Department of Engineering and Public Policy at Carnegie Mellon University where he is also University and Lord Chair Professor in Engineering. In addition, he holds academic appointments in the Department of Electrical and Computer Engineering and in the H. John Heinz III College. His research addresses problems in science, technology and public policy with a particular focus on energy, environmental systems, climate change and risk analysis. Much of his work has involved the development and demonstration of methods to characterize and treat uncertainty in quantitative policy analysis. At Carnegie Mellon, Morgan directs the NSF Climate Decision Making Center and co-directs, with Lester Lave, the Carnegie Mellon Electricity Industry Center. Morgan serves as Chair of the Scientific and Technical Council for the International Risk Governance Council. In the recent past, he served as Chair of the Science Advisory Board of the U.S. Environmental Protection Agency and as Chair of the Advisory Council of the Electric Power Research Institute. He is a Member of the National Academy of Sciences, and a Fellow of the AAAS, the IEEE, and the Society for Risk Analysis. He holds a BA from Harvard College (1963) where he concentrated in Physics, an MS in Astronomy and Space Science from Cornell (1965) and a Ph.D. from the Department of Applied Physics and Information Sciences at the University of California at San Diego (1969).